Reading and Writing in the Service of Inquiry-Based Science

Gina N. Cervetti, P. David Pearson, Marco A. Bravo, and Jacqueline Barber

Reading and Writing in the Service of Inquiry-Based Science

In this paper, we present a working model of the science-literacy interface. This model has guided our development of curriculum units for the *Seeds of Science/Roots of Reading* program and is currently being empirically tested through that program. We believe that we have a genuine contribution to make to the conversation about the science-literacy connection, but believe also that all who care about this interface, ourselves included, need to move beyond theoretical ruminations about the benefits of integration to tough-minded empirical examinations. We are pleased to report that we are in the process of gathering evidence that speaks directly to the science-literacy connection, but our work is still too preliminary to allow us to speak with great confidence about instructional implications and recommendations that could assist teachers in promoting synergy between science and literacy. Nonetheless, we do have a message, in the form of a model that might guide teachers, as it has guided us, in shaping an appropriate and supportive role for text and for literacy practices in inquiry-based science. What we have are some very good hunches that come with several sources of support, none of it definitive but all of it consistent in pointing to these synergies. First, there is a some good theory about the efficacy of integrated curriculum (see Gavelek, Raphael, Biondo, S. M., & Danhua, 2000; Yore, Hand, Goldman, Hildebrand, Osborne, Treagust, & Wallace, 2004). Second is a body of loosely related cognitive research and an even smaller corpus of solid instructional research (e.g., Guthrie & Ozgungor, 2002, and Hapgood, Magnusson, & Palincsar, 2004). Third is the professional wisdom embodied by analyses of the very best practices of our very best teachers (e.g., Pressley, Wharton-McDonald, Rankin, Mistretta, Yokoi, Ettenberger, 1996). Fourth, and most important in shaping this paper, is the insights we have gained as we have tried to develop just such an integrated curriculum.

As literacy educators venturing into the world of science curriculum, we approach our work with the dual recognition of two assertions, one a statement of fact and the other an aspiration.

- The fact: state and federal policies have, for better or worse (mostly worse) marginalized disciplinary curriculum, including science, in deference to a massive devotion to literacy teaching and learning.
- The aspiration: in a perfect (or at least a better) world, language and literacy—like learning—would be regarded as a means to an end rather than an end unto itself.

In that vein, our guiding principle has been the acquisition of the knowledge, skills and dispositions of science as the end, and language and literacy as part of the array of means that can help students achieve that end. For too many years, educators and policy makers have regarded literacy as an end unto itself, as a curricular enterprise on a par with science, social studies, art, or mathematics. As a result we have created curricular structures (e.g., standards, assessments, and mandated curricula) that undercut both disciplinary learning and, ironically, the acquisition of higher literacy skills, such as comprehension, critical literacy, and strategic reading. Only when we return to a more functional view of the role of language and literacy in supporting disciplinary learning can we achieve our goal of an informed citizenry who can use their literacy skills to think critically and flexibly across many domains of knowledge and inquiry. Applying language and literacy tools to science learning, we think, provides precisely the right venue for promoting these lofty but essential educational goals.□

Our journey into the interface of science and literacy begins with a description of the context in which we have conducted our conceptual and empirical work on the science-literacy connection, followed by a brief review of the science-literacy perspectives that have informed our work. Next, the heart of the paper unfolds as a set of insights we have developed as we have carried out our work, and leads to the finale—a promising, but cautiously proposed, set of implications for teaching integrated science-literacy curriculum.□

Context for our Work

Our understanding of the science-literacy interface has developed in the context of our work on an NSF-funded curriculum development and research project, *Seeds of Science/Roots of Reading*, a joint effort of the Graduate School of Education and the Lawrence Hall of Science (LHS) at the University of California, Berkeley. The goal of the project is to transform existing inquiry-based science units from the *Great Explorations in Math and Science* (GEMS) curriculum series developed at LHS into materials that help students make sense of the physical world through firsthand experiences while addressing foundational dimensions of literacy.

Seeds/Roots has assembled science and literacy experts to study, enact in the form of curriculum, and test the limits and potential of the science-literacy interface. The questions that have guided the effort are:

- How can reading and writing be used as tools to support inquiry-based science learning?

- What benefits accrue to reading and writing when they are embedded in inquiry-based science?
- What skills, strategies, and processes are shared by these two curricular domains?

During the first 18 months of the project, we have built a model of science-literacy integration, applied that model to the development of three integrated units for second and third grade students, and carried out a nation-wide field test of these units across 87 classrooms in 21 states. We have also initiated a series of qualitative and quasi-experimental research studies designed to inform our curriculum development work and answer foundational questions about both science and literacy learning in the context of an integrated curriculum. While complete results are not yet available, we can and will share some insights from our preliminary analyses and reflections on our experiences to date.

Related Literature

Relevant Work on the Science-Literacy Interface

Our work draws in part on literature from the 1980's and early 1990's examining the overlapping cognitive demands of science and literacy. For the most part, this work is more conceptual and theoretical than empirical or pedagogical in orientation and consists largely of "insights" into the shared demands and processes of thinking in science and literacy. For example, Padilla, Muth, & Padilla (1991) suggest that discovery science and reading emphasize a shared set of intellectual processes (e.g., observing, classifying, inferring, predicting, and communicating) and that the very same problem-solving processes are used "whether [students are] conducting science experiments or reading assigned science texts" (Padilla et al., 1991). Baker (1991) connects reading and science through metacognition, arguing that science and literacy share a concern with fostering independent learning. Baker suggests that, while metacognition ("the awareness and control individuals have over their cognitive processes") is widely recognized as an essential component of reading, its connection to science has not been explored even though many science process skills can be regarded as highly metacognitive (e.g., formulating conclusions, analyzing critically, evaluating information, recognizing main ideas and concepts, establishing relationships, applying information to other situations). Baker contends that attention to metacognition in science can help teachers foster independence through "lectures, discussion, laboratory work, and hands-on activities" (Baker, 1991, p. 2).

Our work also relies on existing empirically-based models of science-literacy integration (e.g., Palincsar & Magnusson, 2001; Romance and Vitale, 1992; Guthrie and Ozgungor, 2002; Guthrie, Van Meter, Hancock, Alao, Anderson, & McCann, 1998). Among Palincsar and Magnusson's most important contributions, in relation to our work, is their distinction between first and secondhand investigations. In their approach, literacy engages students in secondhand investigations for one of three purposes:

(a) to bolster and reinforce learnings from firsthand investigations,

(b) to take students on vicarious journeys (deep in the ocean, far into outer space, or inside a volcano) that cannot otherwise be taken in our classrooms, and

(c) to provide students with an opportunity to apply the inquiry-based skills and processes acquired in firsthand investigations to new domains of inquiry (e.g., drawing conclusions based on reading an account of an investigation).

Romance and Vitale (1992) take us in a slightly different direction. They were among the first to design and empirically test a science-literacy integrated curriculum that attempted to use vicarious text-based experiences as a 'test bed' for applying knowledge and reasoning skills that students were supposed to have gained in firsthand science investigations. Students in their integrated approach outperformed the control group (side-by-side but thoroughly encapsulated science and literacy curricula) students on standardized measures of reading and science, and they displayed more positive attitudes toward science. Guthrie and his colleagues (e.g., Guthrie and Ozgungor, 2002; Guthrie et al., 1998) have approached the integration of science and literacy from the reading side of the curricular integration and, equally as important, from a perspective that pays as much attention to engagement as it does to cognitive learning. Concept-Oriented Reading Instruction (CORI) places emphasis on providing a rich and compelling context for teaching reading strategies. Inquiry science (or other subject matter foci) serves as the "real-world" interaction ingredient for the CORI model. In the early phases of CORI, they were able to show impressive advantages over conventional approaches on measures of reading comprehension and engagement but failed to examine conceptual learning of science. In their later work they added conceptual science learning to their portfolio of outcomes and found positive results for science as well as literacy.

These few studies are the most notable exemplars in a much larger body of work that has guided our entry into the science-literacy interface. They index at least a few of the points along the broad continuum of views about the ideal relationship between science and literacy. In this work, and among scholars in both science and literacy education who are concerned about the disciplinary interface, there is broad acknowledgement that the work of scientists is reliant in part on their literacy skills, particularly in accessing ideas from text and communicating results. Yore et al. (2004) note that "scientists rely on printed text for ideas that inform their work before, during, and after the experimental inquiries" (p. 348). Kamil and Bernhardt (2004) further suggest that "anyone lacking literacy skills will be unable to access [the scientific] body of knowledge and data" (p. 126).

Despite this recognition that text is a fundamental part of the scientific enterprise, there is equally strong apprehension about the use of text in school science, particularly in the inquiry science tradition and particularly with younger students. Three concerns seem to predominate. First, science texts are more often "declarations of 'fact'" than real representations of the "heart and soul of the scientific enterprise" (Yager, 2004, p. 95). Second, science texts, particularly trade texts, often include misinformation, exaggerations, and other misrepresentations that can interfere with the development of science concepts (Rice, 2002; Rice and Rainsford, 1996). Third, text can eclipse scientific discovery, taking the place of observation and experimentation and supplanting children's involvement in inquiry with passive reception of ideas (Short & Armstrong, 1993; Palincsar & Magnusson, 1997; Peacock & Gates, 2000)

Given these pervasive concerns, it is not surprising that text has been largely absent from inquiry-based science or that, where text is part of the curriculum, it has been relegated to a peripheral position. Even in programs like those of Romance and Vitale (1992) and Guthrie and colleagues (1998) where science and literacy are given comparable status, the firsthand experience component of the integrated curriculum is temporally precedent to the text component.

Insights from our Work in *Seeds/Roots*

In investigating the natural convergences between science and literacy, we found lots of evidence for mutual support, and none was more central than our understanding of the way in which text can support rather than supplant inquiry-based science learning—and appropriately that is our first insight. But as we planned our instruction, as we looked more closely at elements like concept development and vocabulary, comprehension and inquiry skills, visual displays, talk about text and science, we came to understand that, in some important respects, science and literacy are more than supportive and synergistic, that they are in fact *isomorphic*. A careful analysis of which strategies and cognitive processes are shared between science and literacy and which are domain specific, led us to the conclusions that: comprehension strategies *are* inquiry strategies; words *are* concepts; science *is* discourse; and literacy *is* visual literacy. These principles have guided our model of science-literacy integration as we continue to seek strategic opportunities to help students develop their ability to use these common strategies and cognitive processes in both domains. *Seeds/Roots* instructional materials explicitly make the connection between science and literacy strategies and provide time for students to reflect on how those similarities can make their learning more efficient and effective.

Insight #1: Texts can Support Scientific Inquiry

In the inquiry tradition of science education, inquiry is often equated with firsthand involvement in investigations. Secondhand investigations, such as “accounts” of scientific inquiry encountered in text, are generally regarded as poor substitutes for the real thing. And when teachers adopt a strict inquiry approach, text may play little if any role in science learning. As members of the literacy education community, we recognize that there are serious limits to what students can learn about science through text, but just as surely there are limits to what students can learn through an exclusively firsthand approach. Not everything we want students to learn about science can be observed or manipulated in the classroom (and some not in the natural world!). In addition, as Palincsar and Magnusson (2001) point out, it is unlikely that children will come to meaningful understandings in science solely by interacting with materials and phenomena in a firsthand way. Indeed practicing scientists would be the first to admit that text plays a significant role in the development of their own learning, theory development, and methodological expertise. They learn about and come to understand the natural world through text as well as firsthand experience. So too can students, or at least that is our claim and our goal.

Our experience in *Seeds/Roots* suggests that text can serve a number of roles that are supportive of inquiry science—before, during, and after firsthand investigations. In laying out these roles, we once again remind readers of our basic commitment to leading with science and allowing literacy, including texts, to play the supportive role of assisting students in acquiring and organizing facts, concepts, and patterns (see Guthrie, et al, 1998) into networks of meaningful relations.

Providing Context

Facts, concepts, and patterns—the stuff of scientific learning—are grounded in contexts; contexts include the discipline in which the learning is situated, the real world context in which the scientific phenomena operate, and the specific experiential/instructional context in which the learning occurs. And contexts provide a natural link to the knowledge and experience that students bring to both first and secondhand investigations. Text can support firsthand inquiry by providing an invitation for students to engage with the scientific context. Texts that serve this invitational function may engage students by representing new ideas or phenomena in interesting ways or by presenting the familiar in a new, scientific frame—“making the familiar strange” if you will. Text can prepare students for inquiry by inspiring students to wonder about science. In a study by Anderson and colleagues (1997), students read books to provoke their wondering about a scientific topic, asked questions about the topic, and engaged in investigations to answer their questions. Students selected books by asking, “Is this interesting? Does it make us wonder about science things? Do we want to talk about these wonderments with our friends?” (Anderson, West, Beck, Macdonell, & Frisbie, 1997, p. 714). Collectively, they found many books that prompted wonderments, which were sufficiently engaging to lead the students to substantive explorations at a later point.

Text can invite students to engage with the context. The *Seeds/Roots* physical science unit on mixtures includes an introductory book that engages students in thinking about the relationship between properties, materials, and human-made objects by exploring imaginary and imaginative mismatches, such as rain boots made of paper and frying pans made of rubber.

Text can introduce domain and/or context for the unit. The *Seeds/Roots* unit on shorelines includes a book that introduces an array of beaches and shorelines to provide a context for the unit for students who may not have firsthand experiences with shorelines. Every imaginable type of shoreline is represented—tropical, arid, forested, sandy, rocky, agrarian. This book helps set a context for students' investigations of shorelines and the organisms that live there.

Text can connect firsthand investigations to the world outside the classroom. The *Seeds/Roots* shoreline unit includes an activity in which students create a model oil spill in a bucket. This firsthand activity is supported by a book about an oil spill in Spain that helps students connect that firsthand experience with the causes and consequences of a real oil spill in the ocean.

Delivering Content

Text can deliver (some of) the "goods." Text can present scientific concepts, facts, and patterns to students. This is the most traditional role for text in science. And, as Palincsar and Magnusson (2001) suggest, it is an authentic role: "…the notion that inquiry must be exclusively activity based is problematic because, in fact, much of what we know about scientific reasoning has been acquired through the thinking and experiences of others; that is, through learning in a second-hand way. Frequently, although not exclusively, this second-hand learning can be facilitated with the use of text" (Palincsar & Magnusson, 2001, p. 152). All of the books in the *Seeds/Roots* series deliver science information. Some present scientific content incidentally as they, for example, discuss the work of particular scientists. Other books are designed principally for delivering information, including reference readers and "all about" books, such as a book all about plant roots that students read after they have observed and compared several root structures firsthand. The delivery of information is intended to connect, supplement, and extend, not to supplant, students' firsthand investigations.

Texts can make the obscure accessible. Text can provide information about and even illustrate phenomena that would otherwise be unobservable in a classroom context. Phenomena may be unobservable because they are too small, too big, too hidden, or too distant for us to see firsthand. The *Seeds/Roots* mixtures unit includes a book about dissolving, which is designed to help students understand the process of dissolving, including the fact that substances are still present when dissolved in liquid, although they are no longer visible to the naked eye. By providing a model of this invisible phenomenon, this book helps students make sense of their firsthand investigations of mixtures. It also helps them construct an understanding of solubility that is essential to selecting materials for the products they design later in the unit.

Modeling

Both implicitly and explicitly, texts can model important processes in both literacy and science. The models range from inquiry, to reading and writing, and to the nature of science itself.

Texts can model inquiry processes. Text can provide rich models of scientific inquiry skills, including what careful observation involves, how to compare and classify things, as well as how to make inferences and explanations based on evidence. The *Seeds/Roots* series includes several books that describe children or adults engaged in the inquiry or the design process to solve problems. For instance, one book depicts a student observing and recording change over time in one special spot in nature. Students working on the unit use these text-based demonstrations to guide their own investigations.

Texts can model literacy processes. Just as stories kids read provide models for their own narratives, so science texts can provide models of how particular text genres are constructed. Text can also model scientific modes of communication, including evidence-based explanations and argumentation. They can even model the writing process, providing examples of the steps a writer might go through in creating a journal or a report. We have just such a book in our shoreline unit—it chronicles the work of a particular student as he prepares his report on a sea animal. Later, students refer to this book as they prepare their own reports. Texts certainly provide lots of opportunities for students to apply reading strategies, but they can even model steps in the reading process. All of the books in the *Seeds/Roots* series are designed to support students' reading fluency and development of academic language. Most are also designed to provide opportunities for students to practice comprehension strategies, use textual and structural features of informational text to organize and remember information, and observe and engage in successful writing strategies.

Texts can illustrate the nature of science. Text can provide insights into the scientific enterprise and scientific dispositions. Text can model the wondering, exploration, and hypothesis testing that are the heart of scientific literacy (Yager, 2004). Books can model missteps and dead ends, as well as successes of science and the application of scientific work to everyday dilemmas. Text can demonstrate human and commercial uses for science. Each of the *Seeds/Roots* curriculum units includes one or more readers focused on the life and/or work of a particular scientist. The scientists describe their interest in science, demonstrate scientific habits of mind such as persistence and curiosity, and share aspects of their work. These scientists model excitement, passion, and commitment. These biographical sketches are not limited to lives of a few famous scientists but include scientists in different stages of their careers, in different disciplines, and from a diverse array of ethnic backgrounds.

Supporting Second-Hand Inquiry

Texts provide experience with data. Text can provide data on which the reader is challenged to draw conclusions and develop claims. Second-hand investigations can allow students to investigate phenomena that are not easily modeled in classrooms. Text can also help students focus their investigations and set goals for their learning in firsthand investigations. Several of the books in the *Seeds/Roots* series present information and ask students to draw conclusions. In a book about students conducting investigations related to snail habitats, students are asked to draw conclusions based on the data collected by students in the book.

Supporting Firsthand Inquiry

Texts provide information that facilitates firsthand investigations. Texts can help students make sense of their firsthand investigations and draw conclusions about their data. They can provide an opportunity for students to support and/or revise their thinking based on the addition of new information in text. They can address misconceptions that might arise in the conduct of firsthand investigations. In the *Seeds/Roots* shoreline unit, students use a science notebook reader to find information related to the composition and formation of the sand in their investigations.

Insight #2: Comprehension Strategies are Inquiry Strategies

The model of science-literacy integration that guides our work relies on a recognition that science and literacy share a set of core meaning making strategies.

Comprehension strategies and inquiry strategies represent accepted problem-solving and meaning-making strategies in literacy and science respectively. Inquiry is the approach that scientists use to pose questions, investigate phenomena, and make meaning. Comprehension strategies similarly represent an approach to questioning and making sense around text. As the domains of meaning-making in reading and science, comprehension and inquiry share a set of important functions and strategies that, at least in second and third grade, are identical.

Some Shared Functions

- Metacognitive regulation. Comprehension strategies and inquiry strategies share a concern with promoting self-regulation (Baker, 1991). That is, comprehension strategies and inquiry strategies are both designed to help students monitor their learning—to help students plan an approach to the task ahead, evaluate the outcomes of their efforts, and revise them as needed.
- Acquiring information. Comprehension strategies, particularly in informational and content-area literacy, support students' efforts to acquire information. Inquiry shares the goals of gathering and making sense of information in order to construct more complex and complete understandings.
- Solving problems. Problem solving is all about managing complexity. We take a complex domain and make it manageable by attacking one aspect of the problem space at a time. Then we piece the steps and chunks back together. Comprehension and inquiry strategies structure, systematize, and break down and then re-synthesize aspects of reasoning about text or experience in exactly this way. And save for the fact that the information that drives the process comes

from different sources (text versus experience), the overall process looks and feels the same across domains.

- Making connections. Comprehension and inquiry strategies help students bring together diverse sources of information—including text-based information, experience, and personal knowledge—to make judgments and draw conclusions. Comprehension requires a reader to both understand ideas from the text (oh, I get it!), build a coherent account of full array of ideas the text offers (oh, I see, this goes with this) and connect them with other experiences and ideas already available in schema-like structures in long term memory (oh, this is sort of like…). Inquiry requires a scientist to see steps as well as the relationships among the steps of any particular inquiry process and to compare them to previous experiences with similar inquiries.

All of these functions come together around supporting meaning making. While the "doing"/activity element of reading and scientific inquiry look quite different, the meaning making elements share powerful commonalities and can look very much the same. As Pratt and Pratt (2004) note, while the source of learning differs (natural phenomenon as object versus text as object), both "call for the construction of meaning from experience" (p. 396).

Shared Strategies

Comprehension strategies and inquiry not only share overlapping goals and functions, they also share common strategies—strategies that support the construction of meaning. Our emphasis is on encouraging students to engage in meaning making around their hands-on experiences and their reading and to be both active and strategic as they do so. We want to help students connect the strategies to the doing. We find these strategies in both science and literacy activity:

- Activating prior knowledge. When we read, as when we do scientific investigations, it is essential to think about what we know. Activating prior knowledge prepares [students] to make logical connections, draw conclusions, and digest new ideas (Barton, Heidema, and Jordan, 2002, p. 25). In our work, we connect literacy and science by encouraging students to activate their knowledge from text experiences, hands-on experiences, and out-of-school experiences. We also emphasize reviewing prior knowledge in light of new information.
- Establishing Purpose/Goals. In both reading and science inquiry we set explicit goals for what we want to learn and we identify strategies to help achieve those goals.
- Making/Reviewing Predictions. Prediction builds purpose in either domain; you read on or work on to see whether your prediction turns out to be accurate. Prediction builds commitment by giving readers and scientists a "stake" in the outcome.
- Drawing Inferences and Conclusions. An essential goal of science education is to encourage students to weigh evidence and reach defensible conclusions (Watson 1983, p. 62). In reading, drawing conclusions is a valued high-level interpretive skill. In both instances, using evidence to warrant claims is the heart of the activity.
- Making Connections/Recognizing Relationships. When reading and engaging in inquiry, we want students to broaden and deepen their understandings by making

> connections across a range of experiences and information and by discerning relationships of various kinds, including cause and effect relationships and comparison/contrast relationships, among others.

Table 1 illustrates what each of these important strategies looks like when it is instantiated as a prompt designed to provoke students to be more strategic *both* when reading and when engaging in inquiry.

Table 1: Illustrations of the Shared Cognitive Functions of Inquiry and Comprehension Strategies

Shared Strategy	Common Questions	Example in Science	Example in Literacy
Activating prior knowledge	What do I already know? What do I know now that I didn't know before?	Students use an anticipatory chart to monitor their growing knowledge of shorelines and the organisms that live on shorelines.	Before reading a book about earthworms, students discuss what they have learned from their hands-on observations of earthworms.
Establishing purposes-goals	Why am I reading/doing this? What am I trying to learn? What information am I seeking?	Before engaging in guided investigations of their shoreline organisms, students write about what they want to learn through their investigations.	Having investigated the effects of oil spills through a series of hands-on science activities, students discuss what they still want to know before reading the book, *Black Tide*.
Making-reviewing predictions	What do I think is going to happen?	Students continually make, review, and revise their predictions about what will happen in a worm bin—and they document the growing evidence that soil is being made.	Students make predictions about what a habitat scientist is and does before reading the book *Habitat Scientist*; they review and revise those predictions during and after reading.
Drawing inferences and conclusions	What does this mean? How do I explain x?	Students gather evidence from a bucket of beach sand to answer the question, "What is sand made of?"	Students use a scientists' sand journal to make inferences about the origins of sand samples.
Making connections-recognizing relationships	What caused x? How are x and y related? How is x like/unlike y?	Students compare the adaptations of different isopods.	Students use a reference reader about substances to select ingredients that will help them make paint with particular properties.

Insight #3: Words are Concepts

To have active control of a word is to know more than its definition; it is also to know how the word is used in different contexts and where it fits in a rich network of related concepts. Word knowledge is multidimensional (Nagy & Scott, 2000). At its most basic, knowing a word involves knowing how the word sounds or looks when it is written. More sophisticated knowledge of a word might involve knowing its definition. Even more sophisticated knowledge might also involve things like its syntactic register, its context of use, and its association with other words.

In this sense, word knowledge at its most mature is conceptual knowledge—it involves understanding of words as they are situated within a network of other words and ideas (what psychologists have called *paradigmatic* relations)and their relationship to other words in spoken or written contexts (what psychologists have called *syntagmatic* relations).

We suggest that, from this perspective, word learning in science can and should be approached as conceptual learning. Even though it is true that words are labels for concepts, it is better to think of them even more conceptually and to assert that words are concepts that can be connected to other concepts to form rich conceptual networks.

Vocabulary instruction in science has sometimes been reduced to recall or definitional knowledge of a large number of words. Indeed some science text books introduce more new vocabulary than foreign language text books! However, vocabulary instruction at its most complex focuses on a targeted number of words and approaches a depth-of-knowledge criterion that is comparable to that of science conceptual learning. In science (as in other domains), "students should learn concepts as organized networks of related information" (Glynn & Muth, 1994, p. 1060).

We know from a substantial body of research that effective vocabulary instruction integrates new words with other word knowledge (see Nagy, 1988; Stahl & Stahl, 2004). We also know that word learning requires multiple exposures in meaningful contexts:

> For each exposure, the child learns a little about the word, until the child develops a full and flexible knowledge about the word's meaning. This will include definitional aspects, such as the category to which it belongs and how it differs from other members of the category….It will also contain information about the various context in which the word was found, and how the meaning differed in the different contexts. (Stahl & Stahl, 2004, p. 63)

In many ways, science is an ideal context for developing rich conceptual networks of words. Science provides natural opportunities for authentic, repeated and varied encounters with these new words/concepts—during firsthand experiences, through texts, and in discussions and written activities. All of these contexts provide students opportunities to practice using the words in appropriate ways.

In our work, we create opportunities for students to encounter and use a focused set of conceptually core words in discussion and in print. For example, students are introduced to the concept of *habitat* as they simulate a forest floor habitat in building their own terrariums. Students discuss the various elements of a habitat (food, *shelter*, water, air, light) for the *organisms* (plants and animals) they will introduce to the *terrarium*. Further discussions take place about the *soil* the organisms will require and the *nutrients* and *moisture* that the soil will provide the habitat.

Students also read about the concept of *habitat* in the *Talking with a Habitat Scientist* book where they learn that a *habitat* is a place where plants or animals live and find everything they need to *survive*. The book explains how plants and animals *depend* on each other and the *prey/predator* roles they play in the *environment*. Through print, discussion, and firsthand experiences, students learn about the concept of *habitat* in a relation to a conceptual network of other important science words. All of the words in italics above are core concepts for the science unit. Students encounter and learn these words as a connected set of *ideas*.

Insight #4: Science is Discourse

Science is an academic language, a way of communicating about the natural world. In this fourth synergy, we recognize as Gee (2004) does that in addition to being a discipline, science is a social context where the language used is a powerful and specialized way of talking about the world, writing about the world, and even “being” in the world of scientists. The specialized language of science, which linguists call a discourse, has its own vocabulary and organization, which are embodied in the ways scientists communicate about their work. Postman (1979) emphasized this point by claiming that "Biology is not plants and animals. It is language about plants and animals ... Astronomy is not planets and stars. It is a way of talking about planets and stars" (p. 165).

This is very different from older views that treated science and language as existing in separate domains where science was about experience—thinking about or doing science—and not about language at all. Science is, in fact, a highly communicative field with established ways of talking and writing. Lemke (1990) suggests that learning science is learning the language of science.

For example, the need for precision motivates scientists to eschew the vocabulary of everyday language in favor of specialized words that will be clear to other scientists (but are likely to be obscure to the average person). Scientists make predictions rather than guesses, they observe rather than see, and they talk about habitats rather than homes or properties rather than qualities.

But the discourse of science is more than specialized words; it is also about organizing claims and evidence into arguments expressed in a scientific way of "talking" or "writing." The language of science is evident in the way scientists debate and discuss scientific concepts, and in the ways they approach investigations and negotiate meaning by questioning and posing alternative solutions during scientific discourse. Argumentation plays a major role in the social construction of scientific knowledge. Language mediates this process of "supporting, criticizing, evaluating, and refining of ideas, some of which may conflict or compete, about a scientific subject" (Kuhn, 1992).

While this specialized discourse serves the interests of the scientific community, it is generally inaccessible to outsiders, including students in our schools. Yet, the language of science is part and parcel of doing science, and it is one of the many academic discourses that students are expected to understand and use when encountering texts and tests in school. And, talking about science is critical to the social activity involved in science--observing, describing, questioning, evaluating, concluding, arguing, classifying, comparing. In other words, students must learn the various often complex scientific discourse styles, including the vocabulary necessary to share, clarify, and distribute knowledge among peers. For many students, these special discourses become a “Catch 22”. They don’t come to school with the discourse of science already under control, so it is hard for them to just jump in and do and talk science. But unless they just jump in, they are not likely to get better at doing and talking science.

We are committed to demystifying the register and terminology of science so that students can embrace them in the science classroom. We do students a disservice if we do not help them acquire this tool kit for doing science.

One strategy for dealing with the obscurity of scientific discourse is to avoid it or at least delay its use until middle or high school. Our experience with inquiry-based science for young learners suggests, to the contrary, that they benefit from thoughtful immersion in and exposure to the language of science early and often. Just as students deserve a chance to acquire the firsthand tools of inquiry-based science, so too do they deserve a chance to acquire its discourse. Science is a powerful discourse that, among other things, will support their entry into valued disciplines of academic learning. In our own work, we have found that even second and third grade students can appropriate the discourse as they participate in firsthand science if the curriculum is focused and systematic in scaffolding the language use to fit the science goals and processes.

We are committed to a four-pronged approach: (a) create an environment that is rich in the words and linguistic structures of science, (b) select vocabulary representing key concepts in the domain along with key words needed to communicate scientific activities and ideas to others, (c) use everyday language to introduce and build a conceptual bridge to more scientific language, and (d) immerse students in firsthand investigations in a way that binds the language to the activity.

First, we create an environment around science instruction that is replete with the discourse of science. Students encounter the words and linguistic structures of science through books, student sheets, visual displays, and teacher talk.

Second, we have chosen core scientific terms to emphasize both within and across domains. Thus, within the domain of earth science, in a unit on Terrariums, core words include habitat, decomposition, adaptation, ecosystem, evidence, investigate, observe, and classify. Notice that the first four of these words are crucial to the domain of life sciences and will be essential to classroom talk about the activities of the creatures in the terrariums they have built. The second set of four words is not unique to life science; students will encounter them in units across the domains of physical science and earth science.

Third, we use students' existing understandings about language and the world to support their development of scientific language. As we mentioned above, we use everyday language as hooks on which students can "hang" new scientific language. But we also help them understand why and how it makes a difference when you say observe rather than see or look, or when you talk about your data as evidence rather than clues.

Finally, we view firsthand investigations as the glue that binds together all of the linguistic activity around inquiry. The mantra we have developed for ourselves in helping students acquire conceptual knowledge and the discourse in which that knowledge is expressed (including particular vocabulary) is "read it, write it, talk it, do it!"—and in no particular order, or better yet, in every possible order.

Insight #5: Literacy is Visual Literacy

Text, particularly in science, refers to more than words on the printed page. Science relies heavily on the use of visual elements to represent and convey information, and these visual elements are an essential component of science text (Kress, 2000). In science, the diversity of visual elements extends from photographs to highly complex charts, tables, graphs, and diagrams. These visual representations often carry new information that supplements and supports printed text, but sometimes they literally offer *re*-presentations of textual information in a visual format. Both forms of representation—visual and print—are used to communicate complex arrays of ideas, evidence, and claims about natural phenomena. But visual representations also serve a variety of special functions that support students' ability to recognize relationships, solve problems, and draw conclusions.

1. They can condense large amounts of information in ways that facilitates the drawing of conclusions.
2. They can represent relations among facts, concepts, and patterns in a way that increases the likelihood that students will develop a rich and elaborate set of connections among these elements.
3. They make transparent what can otherwise be obscure; this is the maxim that a picture is worth a thousand words.

But these functions apply to more than pictures. A graph, for example, makes the magnitude of a linear relationship between two variables immediately apprehensible in a way that even the most well-crafted sentence cannot. All three of these functions make problem-solving and conceptual understanding all the more likely.

Visual displays also bring variety to the representation of complex ideas and data, increasing opportunities to access that information. In our work, we have been able to identify key roles for at least the following types of visual displays—maps, charts, graphs, and diagrams; moreover, each of these major types has its own subcategories (e.g., within diagrams, we have cross-sectional, venn, and flow).

Despite the centrality of visual information to science, students are not often taught to “read” and interpret these displays (Lowe, 2000). As Lowe (2000) suggests, successful reading of a scientific representations requires different skills from those required for reading other, more "everyday," photographs and illustrations. To “read” visual elements in science requires an understanding of their form, purpose, and function. While we might be more inclined to surround print texts with comprehension instruction and assessment, the centrality of visual texts in science invites an equally strong emphasis on both literal and interpretive comprehension tasks. Either can be examined at “face value” (akin to a literal reading) or from a more interpretive perspective (e.g., how does this display change how we think about X?).

In our work, we teach students to read visual representations, connect them to information provided in the print text (i.e., words arrayed in sentences and paragraphs on the page), and create their own representations as they conduct and communicate their firsthand investigations. For example, in each book that students encounter in our curriculum, teachers are encouraged to provide students with explicit instruction and opportunities to practice reading illustrations, diagrams, and tables. The *Snail Investigations* book, for instance, distills large amounts of data from the investigations of several students by placing data in table format. To help students gain access to this information, teachers are asked to explain the function of tables (make connections between various pieces of information) and how to read the table (the role of row and column headings and how to trace certain findings using these two elements). Students are then encouraged to make conclusions about the investigation outcomes and connect this information to the printed text, where students posed questions they had about snails.

Understanding the form and function of tables in turn, serve as models for students, as they utilize tables to record the outcomes of their own investigations.

Taking Stock

We are very excited about our work and fully committed to seeing it through to the end, or at least to the point where we have lots of empirical data, of both a qualitative and quantitative character, to test the efficacy of our insights. Our hunch is that our insights will be validated by the evidence, but we are not sure and are open to the possibility that we might be wrong. But even at this early point in the research process, the evidence we do have points compellingly to some highly plausible principles to guide us in our quest to improve both literacy and science learning by capitalizing on what each has to offer the other.

Use text, don't avoid it. We are not afraid of using text to support inquiry-based science. We understand—and share—the fear that many science educators have that text will supplant experience as the primary medium for learning science. Our experience tells us that text needn't be regarded as an alternative to science. Instead, it can be a powerful support to inquiry by extending firsthand into secondhand investigations, by helping students travel into spaces where experience cannot easily take them, and by providing an integrative fabric to weave together experiences that might otherwise remain discrete and disconnected.

Celebrate the synergies and isomorphism. At the level of activity and cognitive process, science and literacy are much more alike than different. One of the dangers in offering a separate curriculum for each discipline is that students will learn that it is better to encapsulate the insights from each rather than to search for common processes, strategies, and understandings. Our experience tells us that both literacy and science are supported by integration and shortchanged by encapsulation. While we have emphasized, in this chapter, the ways in which literacy can support inquiry-based science, we could just as easily have emphasized the ways in which learning literacy is enhanced by situating it in the science classroom. Literacy learning benefits when it is enacted as a means to an end rather than an end unto itself. The stuff of science, both content and process, gives meaning and motive to literacy activity.

Emphasize the authenticity of embedding literacy within science. We are convinced that when reading and writing and text are put to service in the interests of acquiring scientific knowledge, they become appropriately contextualized in a school setting. When literacy is encapsulated in its own curricular space (often for 120 to 150 minutes per day because of Reading First), it runs the risk of becoming the curricular “bully” in today’s schools, gobbling up so much of the curricular time and space as to effectively eliminate science, social studies, and the humanities as viable enterprises. The early evidence suggests that both literacy and science benefit when the former is embedded in the latter. We want to opt for the metaphor of literacy as a critical friend (one that can provide support and a lens for reflection) rather than a curricular bully.

References

Anderson, T.H., West, C.K., Beck, D.P. & Macdonell, E.S., Frisbie, D.S. (1997). Integrating reading and science education: on developing and evaluating WEE Science. Journal of Curriculum Studies, 29(6), 711-733.

Baker, L. (1991). Metacognition, reading, and science education. In C.M. Santa and D.E. Alvermann (Eds.), Science learning: Processes and applications. Newark, DE: International Reading Association.

Barton, M. L., Heidema, C., & Jordan, D. (2002). Teaching reading in mathematics and science. Educational Leadership, 60(3), 24-28.

Gavelek, J.R., Raphael, T. E., Biondo, S. M., & Danhua, W. (1999). Integrated literacy Instruction: A review of the literature. Report: Ciera-2-001. 35p.

Gee, J.P. (2004). Language in the Science Classroom: Academic Social Languages as the Heart of School-Based Literacy. In W.E. Saul (Ed.), Crossing borders in literacy and science instruction. Arlington, VA: NSTA.

Guthrie, J.T. & Ozgungor, S. (2002). Instructional contexts for reading engagement. In C.C. Block & M. Pressley (Eds.), Comprehension instruction: Research-based best practices. New York: Guilford Press.

Guthrie, J.T., Van Meter, P., Hancock, G.R., Alao, S., Anderson, E., McCann, A. (1998). Does concept-oriented reading instruction increase strategy use and conceptual learning from text? Journal of Educational Psychology, 90(2), 261-278.

Hapgood, S, Magnusson, S.J., & Palincsar, A.S. (2004). Teacher, text, and experience: A case of young children's scientific inquiry. The Journal of the Learning Sciences, 13(4), 455-505.

Haury, David L (1993). Teaching science through inquiry. Available from ERIC Digests: http://www.ed.gov/databases/ERIC_Digests/index.

Jimenez-aleizandre, M. P., Rodriguez, A. B., & Duschl, R. A. (2000). "Doing the Lesson' or "Doing Science': argument in high school genetics. Science Education.

Kamil, M.L. & Bernhardt, E.B. (2004). The science of reading and the reading of science: Successes, failures, and promised in the search for prerequisite reading skills for science. In W.E. Saul (Ed.), Crossing borders in literacy and science instruction. Arlington, VA: NSTA.

Kress, G. (2000). Multimodality: Challenges to Thinking about Language. TESOL Quarterly, 34(2),337-40.

Kuhn, D. (1992). Thinking as argument. Harvard Educational Review, 62, 155-178.

Kuhn, D. (1993). Science argument: Implications for teaching and learning scientific thinking. Science Education, 77(3), 319-337.

Lemke, J.L. (1990). Talking science: Language, learning, and values. Norwood, NJ: Ablex Publishing.

Lowe, R. (2000). Visual literacy and learning in science. Eric Digest, Report EDO-SE-00-02.

Nagy, W. (1988). Teaching vocabulary to improve reading comprehension. Urbana, IL: ERIC/RCS, NCTE & IRA.

Nagy, W., & Scott, J. (2000). Vocabulary Processes. In M. Kamil, P. Mosenthal, P. D. Pearson, & R. Barr (Eds.), Handbook of reading research, Volume III (pp. 269-284). Mahwah, NJ: Erlbaum.

Padilla, M.J., Muth, K.D., Lund Padilla, R.K. (1991). Science and reading: Many process skills in common? In C.M. Santa & D.E. Alvermann (Ed.), Science learning—Processes and applications (pp. 14-19). Newark, Delaware: International Reading Association.

Palincsar, A.S. & Magnusson, S.J. (1997). The interaction of first and second hand investigations in guided inquiry science teaching. Paper presented at the annual conference of the National Reading Conference, Austin, TX.

Palincsar, A. S. & Magnusson, S.J. (2001). The interplay of firsthand and text-based investigations to model and support the development of scientific knowledge and reasoning. In S. Carver & D. Klahr (Eds.), Cognition and instruction: Twenty five years of progress (151-194). Mahwah, NJ: Lawrence Erlbaum.

Peacock, A. & Gates, S. (2000). Newly qualified primary teachers' perceptions of the roles of text materials in teaching science. Research in Science & Technological Education, 18(2), 155-171.

Postman, N. (1979). Teaching as a conserving activity. New York: Delacorte.

Pratt, H. & Pratt, N. (2004) Integrating science and literacy instruction with a common goal of learning science content. In W.E. Saul (Ed.), Crossing borders in literacy and science instruction. Arlington, VA: NSTA.

Pressley, M., Wharton-McDonald, R., Rankin, J., Mistretta, J., Yokoi, L., & Ettenberger, S. (1996). The nature of outstanding primary-grades literacy instruction. In E. McIntyre & M. Pressley (Eds.), Balanced instruction: Strategies and skills in whole language. Norwood, MA: Christopher-Gordon Publishers, Inc.

Rice and Rainsford (1996). Using children's trade books to teach science: Boon or boondoggle. Paper presented at the Annual meeting of the National Association for Research in Science Teaching, St. Louis, MO.

Rice, D.C. (2002). Using trade books in teaching elementary science: Facts and fallacies. The Reading Teacher, 55(6), 552-565.

Romance, N.R. & Vitale, M.R. (1992). A curriculum strategy that expands time for in-depth elementary science instruction by using science-based reading strategies: Effects of a year-long study in grade four. Journal of Research in Science Teaching, 29(6), 545-554.

Short, K.G. & Armstrong, J. (1993). Moving toward inquiry: Integrating literature into science curriculum. New Advocate, 6(3), 183-200.

Stahl, S.A. & Stahl, K.A. (2004). Word wizards all!: Teaching word meanings in preschool and primary education. In J.F. Baumann & E.J. Kame'enui (Eds.), Vocabulary instruction. New York: Guilford Press.

Van Eemeren, F. H., Walton, D. N., Willard, C. A., Woods, J., & Zarefsky, D. (1996). Fundamentals of argumentation theory: A handbook of historical backgrounds and contemporary developments. Mahwah, NJ: Lawrence Erlbaum Associates.

Watson, F. (1983). On the drawing board: A 21st century curriculum. The Science Teacher, 50(3), 62-63.

Yager, R.E. (2004). Science is not written, but it can be written about. In W.E. Saul (Ed.), Crossing borders in literacy and science instruction. Arlington, VA: NSTA.

Yore, L.D., Hand, B., Goldman, S.R., Hildebrand, G.M., Osborne, J.F., Treagust, D.F., Wallace, C.S. (2004). New directions in language and science education research. Reading Research Quarterly, 39(3), pp. 347-352.